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ABSTRACT

R. C. Blair (1991) developed tables of critical values for the generalized "t" and generalized rank sum tests that do not suffer inflation of Type I error. This study evaluated the critical values generated by Blair for situations in which sample size varies more than a maximum of a factor of two. The accuracy of the values was explored through a Monte Carlo study in which random samples were generated from populations with known characteristics. The variance in each population, the difference in population means, and the sample sizes were manipulated, with 5,000 samples of each size, from 20 size combinations, generated for each condition (equal size and three ratios of unequal sizes). Results suggest that the critical values proposed by Blair maintain the Type I error rate for the generalized t-test and generalized rank sum tests, even with sample ratios as large as 1:8, and with population variance ratios as large as 1:9. Only under small ample conditions with a sample size ratio of 1:8 and with a conservative alpha level of 0.01 did the generalized t-test not control the Type I error rate using these critical values. (Contains four tables and six references.) (SLD)

Evaluation of Proposed Critical Values for the Generalized t and Generalized Rank Sum Procedures Using Unequal Sample Sizes

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Introduction

One of the most fundamental questions asked in educational research concerns the significance of score differences between two populations. While classical hypothesis testing defines the cumulative distribution as $Ho{:}F_Y(w) = F_X(w)$, practically the distribution is more accurately defined as $Ho{:}F_Y(w) = F_X(w - \Delta)$ incorporating a shift in location in one population. If a treatment causes a change in response of exactly Δ units, then the students' t test provides an accurate procedure for comparing the results. However, treatments in reality cause a shift in location that can vary greatly in magnitude. It is not unexpected to see not only a change in location of the two populations but a significant change in variance as well. In this case the student's t-test may well fail to identify important differences.

O'Brien (1988) elegantly explained the issue of nonlinearity in treatment research. The t test is an excellent test of significance for effects that produce a change in location for the dependent variable and if it can be demonstrated that the distributions of the dependent variable are normal, the t test is appropriate. However if the distributions of the dependent variable are normal but differ in both location and scale, the t test may not be useful in determining a significant effect. In this case the conditional log odds is a quadratic function of the ordered data, X, and Z indicating group membership;

$$\Pr(Z = 1|W) = \frac{1}{1 + \exp-\left(\alpha_Q + \beta_Q W + \gamma_Q W^2\right)}. \qquad (1)$$

To test whether the data shift involves both change in location and scale, Z should be regressed against W using a quadratic model;

$$\log odds \Pr(Z = 1|W) = \alpha + \beta W + \gamma W^2. \qquad (2)$$

If the null hypothesis for the quadratic term H_o:($\gamma = 0$) is not rejected, the student's t test is appropriate. However, if the null hypothesis is rejected, there may be a treatment effect operating differentially in the population and the researcher should base the overall test for association on the 2 df test of H_o: $\beta = \gamma = 0$ (O'Brien, 1988). These hypothesis tests may be conducted using either ordinary least squares or logistic regression.

The same type of limitations with respect to nonlinearity are applicable to the rank-sum test which expects the number of Y values occurring between successive X values to decrease or increase linearly. Generally use of the rank-sum test rather than the t test is dictated by nonnormality within either of the two test populations. However when the distributions of the dependent variable are normal and differ in location and scale, the distribution of the dependent variable in the pooled sample will be skewed. That skew will be even more exaggerated in the squared term found in the equation 2 which will tend to diminish the power of the generalized t test. A generalization of the rank sums test may be performed by regressing group membership against the rank and squared rank values.

After independent researchers published results that supported O'Brien's assertions (Tander, Stander & Schwarz, 1990), Blair and Morel (1991) investigated the potential power benefits associated with the generalized tests. They noted that the testing procedure as recommended by O'Brien leads to Type I error inflation. Further study lead Blair (1991) to develop tables of critical values which do not suffer inflation of Type I error. In testing the Type I error inflation, Blair used sample sizes of unequal n up to a maximum of $n_2 = 2n_1$. The intent of this study is to evaluate the critical values generated by Blair for situations in which sample size varies more than a maximum of a factor of two.

Method

The accuracy of the critical values proposed by Blair (1991) were investigated through a Monte Carlo study in which random samples were generated from populations with known characteristics. Three factors were manipulated in this study: (a) the variance in each population, (b) the difference in population means, and (c) the sample sizes. Only normal distributions were examined in this study.

Three levels of population variances were examined, ranging from an equal variance condition (1:1), to a 1:9 ratio of variances (standard deviation ratio of 1:3). These values were used by Blair (1991) in his initial study of the proposed critical values. Also consistent with Blair's initial research, four levels of population mean differences were examined: ranging from a condition of equal population means (0,0), to a condition with population means 3 units apart (0,3). The primary focus of this study, however, was sample size, and the accuracy of the proposed critical values in conditions with sample size differences greater than those examined by Blair (1991). In all, twenty different sample size combinations were examined in this study, including conditions of equal sample sizes (i.e, $n_1 = n_2$), and three ratios of unequal sample sizes: $n_1 = 2n_2$, $n_1 = 4n_2$, and $n_1 = 8n_2$.

Five thousand samples of each size were generated for each condition in the Monte Carlo study. The use of five thousand replications provides maximum 95% confidence intervals of ± .014 around the observed proportion of null hypotheses rejected (Robey & Barcikowski, 1992). In each sample, the generalized t-test and generalized rank sum tests were computed, as were the independent means t-test and Wilcoxon rank-sum test. Generalized test were conducted using linear regression, not logistic regression. The preliminary test for the quadratic term in the generalized tests was conducted at the 0.25 alpha level, as recommended by Blair (1991). The rejection of the null hypothesis for each test was evaluated at nominal alpha levels of .01, .05, and .10.

The Monte Carlo study was conducted using SAS, Versions 6.06 and 6.08. The components of the program were verified by comparing the results with the standard SAS output for benchmark data sets.

Results and Discussion

The Type I error rate estimates are provided in Table 1. The first 20 rows of this table represent the results from conditions in which the population means and population variances were equal, thus representing true null hypotheses for all of the tests examined. The remainder of the table presents results from sampling populations that differed in variances, but did not differ in means. Thus, these conditions represent true null hypotheses for the independent means t-test and the Wilcoxon rank sum test, but false null hypotheses for the generalized tests.

Insert Table 1 about here

When the population means and variances were equal, all of the tests showed good control of Type I error rates at all three nominal alpha levels examined, with only two exceptions. First, the generalized t-test showed excessively high Type I error rates at a nominal alpha level of .01, with sample sizes of (16,2), (24,3), and (32,4). In these conditions, the Type I error estimate reached as high as .032, more than three times the nominal level. These Type I error rate estimates far exceed Bradley's (1978) liberal criterion for robustness (i.e., Type I error is assumed to be reasonably well controlled if $\alpha_{actual} = \alpha_{nominal} \pm 0.5\alpha_{nominal}$). Note however, that adequate Type I error control was maintained at these sample sizes with more liberal nominal alpha levels (.05 and .10). Secondly, the Wilcoxon rank sum was not able to reject any null hypotheses with the smallest sample size (16,2),

at the most conservative alpha level examined (nominal alpha of .01). This is a result of the sampling distribution of the ranks obtained with small and discrepant sample sizes.

As expected, with equal population means, but heterogeneous variances, both the independent means t-test and Wilcoxon's rank sum test showed poor Type I error control when samples were not of equal size. For example, with a nominal alpha level of .05 and population standard deviations of 1:2 (population variance ratio of 1:4), the estimated Type I error rate of the independent means t-test reached as high as .257 with the sample size ratios of 1:8. While the Type I error control of the Wilcoxon test was not as severely affected as that of the t-test, the Type I error rate estimate for the Wilcoxon test in this condition reached as high as .184 with the 1:8 sample size ratios. With the 1:3 population standard deviations, the Type I error control worsened, with the t-test showing a maximum Type I error rate of .395, and the Wilcoxon rank sum test showing a maximum rate of .274. Note that in these conditions of equal means but heterogeneous variances, the null hypothesis that is tested by the generalized tests is false, so the rejection rates reported in the bottom of table 1 represent power instead of Type I error rates.

Tables 2, 3, and 4 present the results from populations with mean differences of 1, 2, and 3, respectively. Because these conditions represent false null hypotheses for all of the tests, the results in these tables represent conditions in which a comparison of statistical power may be conducted. With equal population variances, the independent means t-test and the Wilcoxon rank sum test evidenced a small but consistent power advantage relative to their generalized counterparts. For example, with population means of 0,1 and equal variances (Table 2), the average power of the independent-means t-test at a nominal alpha level of .05, was .739, while that for the generalized t-test was .718 (a 3% increase in power for the independent-means t-test relative to the generalized test). Similarly, the average power of the Wilcoxon test in this condition was .719, while that of the

generalized rank sum test was .679 (a 6% increase in power for the Wilcoxon test relative to the generalized test). Similar slight advantages were evident across nominal alpha levels and across levels of mean differences when the population variances were homogeneous.

Insert Tables 2-4 about here

In contrast, with heterogeneous population variances, substantial power advantages are evident for the generalized t and rank sum tests. With population means of 0,1 and population standard deviations of 1:2 (Table 2), using a nominal alpha level of .05, the average power of the independent-means t-test was .578, while that of the generalized t-test was .774 (a 34% increase in power for the generalized test relative to the independent means t-test). Similarly, in this condition the average power of the Wilcoxon test was .475, while that of the generalized rank-sum test was .642 (a 35% increase in power for the generalized test relative to the Wilcoxon test). Under more extreme heterogeneity, the power advantage of the generalized tests increased. With a 1:3 standard deviation ratio, population means of 0,1 and a nominal alpha level of .05, the average power of the independent means t-test was .457, while that of the generalized t-test was .882 (a 93% power increase). Similarly, the average power of the Wilcoxon test under this condition was .335 while that of the generalized rank sum test was .774 (a 131% power increase). The substantial power advantages of the generalized tests under conditions of heterogeneous variances were maintained across the conditions examined in this study, except (of course) for conditions in which the power for all of the tests approached 1.00 (e.g., most entries in Table 4).

In summary, the results of this research suggest that the critical values proposed by Blair (1991) maintain the Type I error rate for the generalized t-test and generalized rank sum tests, even

with sample size ratios as large as 1:8, and with population variance ratios as large as 1:9. Only under small sample conditions with a sample size ratio of 1:8 and with a conservative alpha level of .01 did the generalized t-test not control the Type I error rate using these critical values. These results extend the usefulness of the critical values proposed by Blair and broaden the range of conditions under which the utility of the generalized tests has been empirically verified.

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Table 1
Type I Error Rate Estimates for Generalized and Regular t and Rank-Sum Tests

			Alpha = .10				Alpha = .05				Alpha = .01			
			Generalized		Regular		Generalized		Regular		Generalized		Regular	
Means	Sigmas	Sizes	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum
0,0	1:1	16, 2	96	63	98	118	65	33	52	52	32	14	9	0
0,0	1:1	16, 4	99	86	99	98	56	41	51	49	14	7	9	11
0,0	1:1	16, 8	98	83	98	105	51	49	50	52	10	6	8	8
0,0	1:1	16,16	104	102	104	108	56	50	53	55	10	10	10	10
0,0	1:1	24, 3	94	74	95	94	55	25	49	45	23	7	7	6
0,0	1:1	24, 6	107	88	104	110	56	45	51	51	13	8	9	9
0,0	1:1	24,12	103	96	100	95	52	46	49	50	12	9	9	12
0,0	1:1	24,24	103	100	104	105	50	49	51	53	8	7	8	10
0,0	1:1	32, 4	106	101	102	106	60	45	53	50	23	8	9	8
0,0	1:1	32, 8	100	95	94	93	50	44	45	47	15	9	9	10
0,0	1:1	32,16	106	95	103	101	52	48	50	49	10	7	9	9
0,0	1:1	32,32	97	99	95	95	47	49	47	50	8	9	8	10
0,0	1:1	48, 6	100	96	100	98	52	51	51	51	14	5	9	8
0,0	1:1	48,12	101	97	98	101	50	44	47	49	14	8	10	8
0,0	1:1	48,24	98	97	96	101	52	51	50	53	11	10	11	11
0,0	1:1	48,48	100	94	98	97	51	49	50	48	10	10	9	9
0,0	1:1	64, 8	109	106	105	111	60	53	56	52	15	10	12	12
0,0	1:1	64,16	105	99	103	98	55	49	51	48	14	10	12	11
0,0	1:1	64,32	97	92	95	94	48	47	46	47	10	9	10	10
0,0	1:1	64,64	93	101	93	98	46	47	45	49	10	10	9	8
0,0	1:2	16, 2	475	255	346	279	404	208	257	184	269	86	126	0
0,0	1:2	16, 4	498	288	271	168	390	203	185	109	218	93	80	45
0,0	1:2	16, 8	499	355	189	159	368	261	113	88	165	115	35	23
0,0	1:2	16,16	414	423	108	113	271	304	56	63	86	132	14	16
0,0	1:2	24, 3	549	302	339	216	473	198	255	147	343	116	123	49
0,0	1:2	24, 6	611	377	274	193	517	291	189	116	339	147	87	37
0,0	1:2	24,12	644	488	189	150	519	374	113	87	291	203	38	28
0,0	1:2	24,24	637	617	94	106	485	497	51	55	217	281	10	13
0,0	1:2	32, 4	608	365	324	199	539	260	239	126	409	134	124	53
0,0	1:2	32, 8	694	458	269	192	610	348	191	115	434	198	85	37
0,0	1:2	32,16	769	597	188	150	661	492	114	82	425	302	34	24
0,0	1:2	32,32	816	773	101	116	689	678	49	60	403	452	7	12
0,0	1:2	48, 6	716	430	334	216	649	336	245	134	514	185	129	46
0,0	1:2	48,12	841	616	283	193	780	514	190	123	627	331	91	42
0,0	1:2	48,24	922	797	175	147	862	711	110	87	700	527	34	24
0,0	1:2	48,48	970	935	97	110	930	892	50	59	753	746	11	14
0,0	1:2	64, 8	796	522	334	205	750	430	247	125	638	261	128	50
0,0	1:2	64,16	904	725	262	175	862	630	175	106	743	450	72	32
0,0	1:2	64,32	971	898	186	145	950	845	107	84	855	702	32	23
0,0	1:2	64,64	995	982	102	118	987	967	56	62	927	898	10	15
0,0	1:3	16, 2	698	424	478	354	642	378	395	274	491	163	246	0
0,0	1:3	16, 4	764	500	357	192	683	397	274	139	470	252	151	76
0,0	1:3	16, 8	757	647	217	179	640	546	140	102	369	348	49	31
0,0	1:3	16,16	694	792	111	126	531	696	59	71	219	451	14	20
0,0	1:3	24, 3	793	465	459	237	741	366	376	181	615	266	233	89
0,0	1:3	24, 6	881	645	347	214	819	550	264	147	647	370	139	47
0,0	1:3	24,12	911	828	216	168	836	756	139	101	615	579	54	36
0,0	1:3	24,24	917	956	99	127	828	915	50	69	553	787	12	17
0,0	1:3	32, 4	865	589	454	215	827	468	367	148	728	301	227	77
0,0	1:3	32, 8	946	767	348	217	905	684	267	143	796	510	137	51
0,0	1:3	32,16	967	923	217	171	934	880	138	105	795	755	54	34
0,0	1:3	32,32	986	992	96	123	953	981	49	65	813	939	11	19
0,0	1:3	48, 6	939	711	450	241	920	628	362	170	865	443	227	65
0,0	1:3	48,12	986	904	344	216	975	855	257	145	928	733	135	57
0,0	1:3	48,24	998	991	214	171	995	981	139	106	964	935	54	40
0,0	1:3	48,48	999	1000	97	124	996	999	46	66	977	995	8	13
0,0	1:3	64, 8	973	806	442	234	964	738	353	154	932	578	218	62
0,0	1:3	64,16	999	962	327	213	997	942	247	139	985	869	129	51
0,0	1:3	64,32	1000	999	197	165	999	997	127	103	994	988	47	33
0,0	1:3	64,64	1000	1000	107	133	1000	1000	53	72	998	1000	13	20

Note. Estimates have been multiplied by 1000 and rounded. Each estimate is based on 5000 samples.

Table 2
Power Estimates for Generalized and Regular t and Rank-Sum Tests

			Alpha = .10				Alpha = .05				Alpha = .01			
			Generalized		Regular		Generalized		Regular		Generalized		Regular	
Means	Sigmas	Sizes	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum
0,1	1:1	16, 2	313	216	342	358	234	143	237	220	148	87	80	0
0,1	1:1	16, 4	497	456	537	504	364	309	402	375	170	107	173	166
0,1	1:1	16, 8	693	646	728	711	569	533	603	585	303	259	335	321
0,1	1:1	16,16	849	820	868	849	752	723	779	764	501	477	531	521
0,1	1:1	24, 3	424	349	466	427	311	189	339	288	178	82	136	71
0,1	1:1	24, 6	653	597	688	666	514	472	555	525	284	203	302	259
0,1	1:1	24,12	850	826	874	850	759	721	789	757	521	475	550	532
0,1	1:1	24,24	951	936	960	950	909	893	922	910	758	727	782	770
0,1	1:1	32, 4	551	522	583	560	423	346	459	418	251	119	223	171
0,1	1:1	32, 8	770	734	800	777	661	601	692	660	408	326	437	395
0,1	1:1	32,16	930	908	942	929	871	840	892	873	681	638	707	686
0,1	1:1	32,32	988	980	991	986	972	961	978	972	897	870	909	895
0,1	1:1	48, 6	714	675	744	719	592	540	625	595	361	241	377	321
0,1	1:1	48,12	905	880	921	906	839	797	859	841	631	557	663	617
0,1	1:1	48,24	986	980	989	984	968	957	976	969	895	865	908	894
0,1	1:1	48,48	999	998	999	999	998	996	998	998	985	977	989	986
0,1	1:1	64, 8	821	788	837	822	715	673	742	709	487	394	509	459
0,1	1:1	64,16	958	944	967	958	924	898	935	919	795	749	816	790
0,1	1:1	64,32	998	997	999	999	994	991	996	995	963	953	970	967
0,1	1:1	64,64	1000	1000	1000	1000	1000	1000	1000	1000	999	997	999	999
0,1	1:2	16, 2	557	313	438	350	483	260	346	257	333	137	195	0
0,1	1:2	16, 4	635	441	465	328	537	337	371	251	326	180	212	137
0,1	1:2	16, 8	683	546	505	431	558	441	394	316	311	239	205	147
0,1	1:2	16,16	672	666	543	519	529	541	403	400	252	275	191	199
0,1	1:2	24, 3	649	385	485	318	574	277	400	239	432	183	238	109
0,1	1:2	24, 6	749	543	543	414	662	455	447	324	483	269	284	144
0,1	1:2	24,12	826	702	616	519	730	604	507	405	497	400	298	224
0,1	1:2	24,24	868	850	692	666	768	767	565	543	480	534	317	322
0,1	1:2	32, 4	730	486	536	358	662	363	443	261	530	206	284	129
0,1	1:2	32, 8	827	656	598	472	760	555	505	362	607	362	330	186
0,1	1:2	32,16	910	824	698	604	848	749	596	488	669	570	395	293
0,1	1:2	32,32	955	942	796	772	899	900	696	665	702	745	456	444
0,1	1:2	48, 6	835	608	596	436	788	513	515	335	687	333	364	173
0,1	1:2	48,12	934	802	713	575	898	727	627	470	797	556	450	272
0,1	1:2	48,24	986	951	832	759	967	917	753	657	891	811	564	444
0,1	1:2	48,48	997	996	930	903	991	989	870	839	937	951	681	647
0,1	1:2	64, 8	898	712	672	506	865	630	592	398	785	454	431	221
0,1	1:2	64,16	976	896	793	680	963	846	730	578	911	715	569	371
0,1	1:2	64,32	997	983	908	858	993	972	861	786	971	923	703	579
0,1	1:2	64,64	1000	1000	972	964	1000	999	942	925	991	992	827	799
0,1	1:3	16, 2	729	452	524	386	679	404	441	312	526	198	301	0
0,1	1:3	16, 4	787	531	447	255	706	435	357	194	505	282	222	118
0,1	1:3	16, 8	797	703	388	313	688	606	290	214	420	409	143	100
0,1	1:3	16,16	768	852	350	351	604	761	236	244	280	515	92	102
0,1	1:3	24, 3	823	509	526	295	781	407	449	233	657	298	308	126
0,1	1:3	24, 6	907	688	485	328	855	595	403	241	704	427	252	94
0,1	1:3	24,12	929	873	448	355	868	808	350	260	654	645	193	131
0,1	1:3	24,24	941	976	449	440	873	951	329	325	608	843	142	157
0,1	1:3	32, 4	886	634	543	295	851	527	466	218	764	357	331	128
0,1	1:3	32, 8	953	807	508	363	926	737	423	274	820	569	287	131
0,1	1:3	32,16	980	953	523	413	954	924	416	317	834	825	242	165
0,1	1:3	32,32	989	995	549	528	967	991	418	408	840	963	205	211
0,1	1:3	48, 6	958	750	565	350	942	676	492	265	887	515	350	138
0,1	1:3	48,12	994	932	590	422	987	901	506	335	949	798	360	179
0,1	1:3	48,24	999	996	630	540	996	990	534	434	973	970	352	244
0,1	1:3	48,48	1000	1000	697	672	999	1000	576	550	984	999	330	316
0,1	1:3	64, 8	981	852	607	395	973	795	537	299	950	663	401	155
0,1	1:3	64,16	998	980	648	490	996	963	577	385	989	919	424	214
0,1	1:3	64,32	1000	999	707	606	999	999	617	504	994	994	431	310
0,1	1:3	64,64	1000	1000	814	776	1000	1000	715	681	1000	1000	486	470

Note. Estimates have been multiplied by 1000 and rounded. Each estimate is based on 5000 samples.

Table 3
Power Estimates for Generalized and Regular t and Rank-Sum Tests

			Alpha = .10				Alpha = .05				Alpha = .01			
			Generalized		Regular		Generalized		Regular		Generalized		Regular	
Means	Sigmas	Sizes	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum
0,2	1:1	16, 2	779	634	818	800	691	529	702	653	555	385	431	0
0,2	1:1	16, 4	950	916	961	947	892	824	919	884	722	564	750	696
0,2	1:1	16, 8	995	990	997	996	988	982	991	989	942	906	953	943
0,2	1:1	16,16	1000	1000	1000	1000	999	999	1000	999	996	994	996	996
0,2	1:1	24, 3	917	825	938	912	854	700	880	823	718	504	681	478
0,2	1:1	24, 6	994	984	996	992	983	964	989	979	923	836	939	895
0,2	1:1	24,12	1000	999	1000	1000	999	998	1000	999	996	992	997	996
0,2	1:1	24,24	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,2	1:1	32, 4	964	941	975	962	929	871	946	924	842	667	835	737
0,2	1:1	32, 8	999	998	999	999	998	993	999	997	985	959	990	978
0,2	1:1	32,16	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	1000	1000
0,2	1:1	32,32	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,2	1:1	48, 6	998	993	998	997	992	983	996	991	963	897	971	941
0,2	1:1	48,12	1000	1000	1000	1000	1000	1000	1000	1000	999	998	1000	999
0,2	1:1	48,24	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,2	1:1	48,48	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,2	1:1	64, 8	1000	999	1000	1000	999	997	999	999	994	981	996	988
0,2	1:1	64,16	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,2	1:1	64,32	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,2	1:1	64,64	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,2	1:2	16, 2	742	503	678	574	678	435	595	471	515	309	413	0
0,2	1:2	16, 4	853	712	788	633	787	608	713	531	596	375	530	366
0,2	1:2	16, 8	926	849	900	837	872	775	841	749	697	582	665	536
0,2	1:2	16,16	969	958	965	952	933	917	932	912	783	749	789	762
0,2	1:2	24, 3	829	597	760	582	780	481	692	494	663	359	531	288
0,2	1:2	24, 6	938	833	890	787	902	759	837	689	787	580	690	460
0,2	1:2	24,12	983	961	969	937	968	931	943	892	891	822	850	751
0,2	1:2	24,24	998	996	997	995	993	989	992	983	952	944	947	930
0,2	1:2	32, 4	904	748	838	685	870	648	784	570	778	462	640	386
0,2	1:2	32, 8	977	920	942	873	959	873	916	804	903	728	816	615
0,2	1:2	32,16	996	990	992	976	991	980	984	958	966	931	939	868
0,2	1:2	32,32	1000	1000	1000	999	999	999	999	998	993	992	987	981
0,2	1:2	48, 6	961	872	915	802	947	813	880	730	901	664	784	524
0,2	1:2	48,12	996	980	987	953	994	967	978	924	980	911	939	810
0,2	1:2	48,24	1000	999	999	997	1000	999	998	994	998	993	993	973
0,2	1:2	48,48	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
0,2	1:2	64, 8	991	945	965	896	984	911	948	835	966	819	890	671
0,2	1:2	64,16	999	994	996	983	999	991	991	970	996	973	979	909
0,2	1:2	64,32	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	1000	994
0,2	1:2	64,64	974	982	946	931	950	969	910	901	868	915	835	836
0,2	1:3	16, 2	797	532	642	495	752	485	567	421	602	299	426	0
0,2	1:3	16, 4	871	669	649	433	805	583	575	346	627	398	424	239
0,2	1:3	16, 8	896	841	716	613	825	764	623	504	593	561	420	297
0,2	1:3	16,16	915	950	801	772	826	899	699	665	551	699	443	429
0,2	1:3	24, 3	881	595	675	437	846	501	613	372	753	386	490	232
0,2	1:3	24, 6	952	811	747	567	916	740	676	470	799	578	523	260
0,2	1:3	24,12	974	955	834	735	943	922	766	641	833	828	595	458
0,2	1:3	24,24	988	996	921	891	967	992	858	825	828	950	660	638
0,2	1:3	32, 4	937	729	734	481	916	630	671	377	844	467	544	245
0,2	1:3	32, 8	985	906	814	658	965	855	761	564	915	730	619	365
0,2	1:3	32,16	995	991	908	838	988	981	865	761	935	939	724	568
0,2	1:3	32,32	998	1000	970	956	994	1000	941	917	962	995	825	787
0,2	1:3	48, 6	979	858	807	594	973	799	757	501	942	666	646	327
0,2	1:3	48,12	999	974	895	775	996	957	860	694	979	901	758	514
0,2	1:3	48,24	1000	1000	972	930	1000	999	953	887	994	995	879	754
0,2	1:3	48,48	1000	1000	996	991	1000	1000	992	980	998	1000	954	933
0,2	1:3	64, 8	994	927	855	670	992	901	814	581	980	807	721	392
0,2	1:3	64,16	1000	995	949	863	999	992	924	796	997	974	857	638
0,2	1:3	64,32	1000	1000	993	975	1000	1000	986	954	1000	1000	951	874
0,2	1:3	64,64	1000	1000	1000	999	1000	1000	999	996	1000	1000	994	984

Note. Estimates have been multiplied by 1000 and rounded. Each estimate is based on 5000 samples.

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Table 4
Power Estimates for Generalized and Regular t and Rank-Sum Tests

			Alpha = .10				Alpha = .05				Alpha = .01			
			Generalized		Regular		Generalized		Regular		Generalized		Regular	
Means	Sigmas	Sizes	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum	t-test	Rank Sum
0,3	1:1	16, 2	977	922	984	974	959	872	962	933	903	760	843	0
0,3	1:1	16, 4	1000	998	1000	1000	999	991	999	997	984	940	989	973
0,3	1:1	16, 8	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	1000	1000
0,3	1:1	16,16	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:1	24, 3	998	985	999	996	995	967	996	987	983	909	979	890
0,3	1:1	24, 6	1000	1000	1000	1000	1000	1000	1000	1000	1000	996	1000	998
0,3	1:1	24,12	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:1	24,24	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:1	32, 4	1000	999	1000	1000	1000	996	1000	999	997	976	998	985
0,3	1:1	32, 8	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:1	32,16	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:1	32,32	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:1	48, 6	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	1000	1000
0,3	1:1	48,12	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:1	48,24	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:1	48,48	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:1	64, 8	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:1	64,16	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:1	64,32	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:1	64,64	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:2	16, 2	895	713	869	780	861	653	817	701	742	537	670	0
0,3	1:2	16, 4	967	904	960	864	945	845	928	799	846	651	828	658
0,3	1:2	16, 8	995	984	995	983	990	968	988	967	951	896	948	883
0,3	1:2	16,16	1000	999	1000	999	999	997	1000	996	989	980	990	986
0,3	1:2	24, 3	955	802	938	814	937	726	909	757	874	611	818	564
0,3	1:2	24, 6	996	975	992	966	992	956	985	939	969	867	955	808
0,3	1:2	24,12	1000	999	1000	998	1000	996	999	995	997	985	995	980
0,3	1:2	24,24	1000	1000	1000	1000	1000	1000	1000	1000	1000	999	1000	999
0,3	1:2	32, 4	988	936	979	910	980	891	964	838	952	758	910	683
0,3	1:2	32, 8	1000	994	999	989	999	987	997	980	996	955	988	924
0,3	1:2	32,16	1000	1000	1000	1000	1000	1000	1000	1000	999	999	999	997
0,3	1:2	32,32	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:2	48, 6	999	981	995	971	997	967	990	946	992	919	974	860
0,3	1:2	48,12	1000	1000	1000	999	1000	1000	1000	998	1000	996	999	989
0,3	1:2	48,24	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:2	48,48	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:2	64, 8	1000	997	1000	995	999	993	999	988	998	978	997	944
0,3	1:2	64,16	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	999
0,3	1:2	64,32	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:2	64,64	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:3	16, 2	867	626	766	627	836	576	701	553	697	429	571	0
0,3	1:3	16, 4	936	797	837	628	894	724	778	543	757	542	640	420
0,3	1:3	16, 8	969	941	926	860	938	896	882	778	801	765	732	587
0,3	1:3	16,16	986	990	980	961	967	976	954	928	861	905	840	800
0,3	1:3	24, 3	944	714	836	621	923	627	792	558	849	521	689	406
0,3	1:3	24, 6	982	921	917	788	967	880	883	716	909	751	788	486
0,3	1:3	24,12	995	992	978	935	990	983	959	893	948	939	891	770
0,3	1:3	24,24	999	1000	998	996	998	1000	995	989	983	995	968	951
0,3	1:3	32, 4	977	863	897	686	967	796	859	580	929	647	772	440
0,3	1:3	32, 8	997	973	962	883	994	955	946	828	971	892	883	663
0,3	1:3	32,16	1000	999	996	979	999	998	991	961	991	990	964	895
0,3	1:3	32,32	1000	1000	1000	999	1000	1000	999	998	998	1000	993	987
0,3	1:3	48, 6	996	946	956	828	993	916	938	763	984	831	885	601
0,3	1:3	48,12	1000	999	994	962	1000	996	990	938	997	986	973	848
0,3	1:3	48,24	1000	1000	999	997	1000	1000	999	994	1000	1000	996	976
0,3	1:3	48,48	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0,3	1:3	64, 8	1000	980	979	903	1000	969	971	854	998	932	940	700
0,3	1:3	64,16	1000	999	999	987	1000	999	998	975	999	997	993	923
0,3	1:3	64,32	1000	1000	1000	1000	1000	1000	1000	999	1000	1000	999	996
0,3	1:3	64,64	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

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